A WEATHER ROUTING TOOL FOR UNMANNED AND MANNED AIRCRAFT SYSTEMS

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1. INTRODUCTION

Operationally today for manned and unmanned aircraft flights, mission planning and flight route weather information in the U.S. Army and across much of the Department of Defense (DOD) are conveyed to the planners and pilots via a standard pilot weather briefing form. This form presents information primarily in text format or with simple map sketches covering broad flying regions and across extended timeframes. It is left to the mission planners and pilots to infer the specific meteorological (Met) conditions along the intended route at the time the aircraft arrives at particular waypoints and en-route stops, and the impact of those conditions on the mission. These types of deductions can be extremely difficult, particularly for the meteorological layman. For operators of Unmanned Aircraft Systems (UAS), discerning the Met effects on their aircraft can be particularly cumbersome since there is no pilot in the aircraft to visually observe the prevailing conditions.

The incorporation of state-of-the-art weather information into pre-flight and en-route flight operations lags at times far behind the aircraft and sensor technologies currently employed by the DOD and those planned for future fielding.

Within the Test and Evaluation (T&E) community, Met conditions and forecasts are normally provided by Test Range personnel; the content and formats varying somewhat from Range-to-Range. However, for UAS-related testing in which the authors and their colleagues have participated; it has been noted that the highly-specific, fine-scale Met data needed to accommodate the small unmanned aircraft and their delicate on-board systems has been largely lacking.

The current inability to provide accurate and detailed route weather information, potential airframe and aircraft system impacts, and alternative routing options represents a serious lack of capability that reduces mission success rates. The incorporation of state-of-the-art weather information into pre-flight and en-route flight operations lags at times far behind the aircraft and sensor technologies currently employed by the DOD and those planned for future fielding.

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Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **JAN 2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **A Weather Routing Tool for Unmanned and Manned Aircraft Systems**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Research Laboratory,AMSRD-ARL-CI-EM,White Sands Missile Range,NM,88002-5501**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **Live-Virtual Constructive Conference, 12-15 Jan 2009, El Paso, TX**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The technology of automated route planning for military and civilian aviation applications has reached a stage of considerable maturity, due in part to the needs of computing, the Internet, and computer games. Routing is needed on the Internet to plan the paths by which messages are sent from one location to another. Computer games use automated routing techniques to move characters around the screen, while the computing process itself may use automated routing techniques to plan the execution of interdependent bits of program code. Applying these techniques to the aircraft routing problem requires at least the following components: a database of current and projected weather and weather effects on specific aircraft in a flight's four-dimensional (4-D) airspace domain (the three spatial dimensions plus time), the planned route of the specific aircraft, and a method for generating and comparatively evaluating potential alternate flight paths.

A new Aviation Weather Routing Tool (AWRT) developed by the U.S. Army Research Laboratory (ARL) addresses the complexity of routing aircraft around adverse weather conditions for a 4-D flight route. The AWRT applies rules-based and physics-based prediction methods to generate atmospheric impacts along the given flight path and for the required forecast period. A route optimization scheme is then used to determine the best alternate routing for aircraft missions if adverse weather will be encountered. The AWRT also takes into account all aspects of the flight mission profile, from launch to recovery, at waypoints along the route, and at all flight altitudes, thus providing a true mission planning and execution routing tool for all aircraft.

2. AUTOMATED AND OPTIMIZED AIRCRAFT ROUTING

For the Army implementation of AWRT, regional mesoscale model and nowcast forecast grids supply pertinent data to populate the 4-D weather data volume with required raw and post-processed parameters. These forecast data parameters are applied to critical aircraft thresholds such as icing, turbulence, convection, Instrument Flight Rules (IFR) conditions, winds aloft, surface crosswinds, etc., along a flight path. When critical weather thresholds are identified, the specific points are labeled to show favorable, marginal, and unfavorable (or adverse) hazardous flight weather, depending on the exceeded threshold. Thus, a tailored flight route weather effects field is created for each aircraft based on the aircraft's specific weather sensitivity thresholds (Knapp, et al. 2006). The three conditions (favorable, marginal, and unfavorable) are color-coded, by map grid cell, on a map background (green, amber, and red, respectively).

Assuming a desired flight path traversed through adverse weather conditions, the "best" or a "good enough" flight path is calculated via a cost function for each potential alternate path. In principle, such a cost function can reflect not only weather effects but other constraints such as restricted flight corridors due to air traffic conflicts or aircraft saturation, or restricted airspace due to any of a variety of other reasons.

The initial implementation of AWRT is intended to reflect only the basics plus weather – don't fly into the ground (or mountain), don't run out of fuel, and minimize adverse weather impacts. Future implementations will also consider closed/restricted airspace constraints and related topics where the routing algorithms will "know" to avoid such identified off-limits regions.

The cost function is computed by associating a cost with each grid element traversed. In most cases, the path cost will be the sum of the costs associated with each incremental element of the path. In order to find an optimal path for an aircraft's mission, the weather and weather effects databases must include the mission launch, recovery, and en-route waypoints and/or other significant route points, as well as the intervening volume. This volume is divided up in the database into grid cells, with this grid searched for the best aircraft path.

The A* (A-star) algorithm is used to calculate optimized aircraft paths around adverse weather conditions. A detailed discussion of A* can be found in Patel (2006). Our implementation of A* combines a minimum weather effects cost function with a shortest distance heuristic. It always searches the shortest distance direction first, so that it wastes less time searching directions leading away from the target than a pure "breadth first," or Dijkstra, algorithm. Like the Dijkstra algorithm, A* will find the shortest path.

Several complexities come into play when attempting to apply the A* technique to aircraft routing. The primary issue is routing through 3-D space, or 4-D space if changing weather conditions over time are considered. This is not an obstacle in any fundamental sense, but it does mean that the number of search space cells to be explored grows with distance at a more rapid rate than for 2-D routing. Thus, the advantage of an algorithm like A* using a distance-to-target heuristic tends to be more pronounced compared to other methods. The cost function becomes more complex, since weather effects don't merely slow the aircraft's progress, but frequently pose a threat to its survival or mission success. But the computational burden caused by such complexities for using A* for one or many simultaneous routes are not a factor on today's high performance computing systems, or even on computers as small as an efficient standard laptop PC system. The application of A* for the AWRT results in often very impressive solutions, considering all factors to a degree impossible for any human analyst, aviation weather forecaster, mission planner, or pilot.

3. AWRT IMPLEMENTATION

The initial implementation of AWRT considers the following:

- Priority is given to unfavorable impacts over marginal impacts in the weather effects en-route calculations.
- Altitude restrictions are user-defined and accounted for.
- Flight time is accounted for using ground distance traveled as well as wind information to calculate airspeed. A constant (user-defined) airspeed is assumed. Future upgrades of AWRT

will consider varied airspeeds in different flight segments, and will also integrate a fuel consumption algorithm.

- The degree of acceptable risk can be user-defined and determines the relative weight assigned to weather impacts as opposed to flight time. So a “careful” path will take more time to avoid weather impacts, while a more “risky” path will attempt to save time by cutting through small patches of harsher weather. Distance traveled is a cost that tends to decrease the length of the resulting optimized path. The magnitude of this cost is determined by the amount of risk a mission can tolerate. The higher the risk, the more weight will be placed on distance as opposed to the other factors, making for a shorter flight path, but one with higher potential of passing through adverse conditions.
- The weather database deriving the weather effects grids for a mission is accounted for by choosing forecast model data times closest to the aircraft’s time and location in the flight plan, which is adjusted granularly for each new cell that the aircraft passes through.

Given a forecast model’s gridded output file, AWRT has been run on small computers used to generate optimized flight paths one mission at a time. Using software to convert the model grids to weather effects along a flight path for a specified aircraft’s weather sensitivity thresholds, a user can manually use a mouse to point-and-click route takeoff and landing locations on a map display, plus en-route waypoints with corresponding flight altitudes. Weather effects are then calculated at model grid points along the path, and color-coded flight route weather effects are displayed. Such a depiction is seen for weather thresholds applied to the Predator unmanned aircraft in Fig 1,. Based on this initial flight route weather impacts assessment, the user can choose to run the AWRT’s route optimization capability, thus producing a flight route based on the user’s risk and altitude constraints. The optimized flight route based on the initial desired route shown in Fig. 1 is depicted in Fig. 2. Another display capability available via AWRT is a 2-D vertical slice of weather effects along a flight path. Fig. 3 depicts such a display for a case unrelated to the case presented in Figs. 1 and 2, showing an aircraft’s optimized flight route over unfavorable (red) conditions between two points.

Figure 1. En-route flight weather impacts for a modeled Predator unmanned aircraft flight from A to B across southern New Mexico, 0600 UTC, 30 August 2006. Green = favorable weather conditions, Yellow = marginal conditions, and Red = unfavorable conditions.

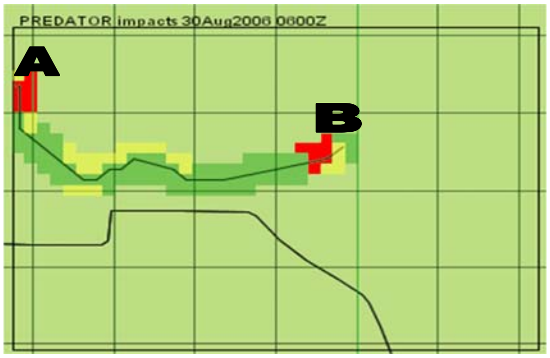

Figure 2. Optimized flight path from Fig 1. Color coding same as Fig 1.

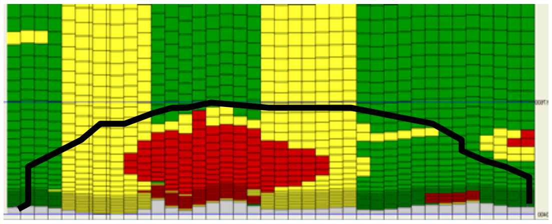

Figure 3. 2-D cross section view along a sample flight path such as that presented in Fig 2. Vertical axis is height, horizontal axis is terrain (gray color) under the flight path. Color coding of weather impacts same as Figs 1 and 2.

While the initial prototype implementation of AWRT has been accomplished for hosting on small personal computers, work is underway to host the capability on more powerful systems capable of handling multiple flight routes to optimize in a given airspace. Implementation options include a web-based version where the AWRT is hosted on a main server which allows users access via a web page interface to input flight planning route information. Such data are then passed to the AWRT server at a centralized location where the software is run to produce optimized flight route options which would then be shipped via alpha-numerics and/or web page graphical display back to the user. Another implementation would be similar to the current PC or laptop-based system, where all necessary software resides locally with necessary forecast data grids over a desired domain being shipped to the local system from an external source. Current work is underway to implement the AWRT operationally within the Army on weather forecaster workstations as well as web-enabling the capability on servers located at a centralized facility so users can access AWRT via the Internet.

In addition to the 2-D graphic depictions of AWRT output shown in Figs 1-3, mission planning flight visualizations have also been developed using the Satellite Tool Kit (STK) software from Analytical Graphics, Inc. This package enables the integration of the flight route with weather impacts color-coded gridding and highly detailed local terrain features to provide mission planners and pilots a cockpit and bird's eye view of the expected weather hazards en-route for the planned flight. A demo of the visualization capability on a laptop PC accompanies the poster presentation of this paper at the conference. While applying AWRT to shorter Army-specific mission oriented flight plans was the initial goal of this work, AWRT has also been applied to long-distance flights such as those routinely flown by civilian airlines and DOD aircraft, with global-scale hemispheric meteorological models and regional mesoscale models providing the weather forecast gridded parameters for AWRT use.

A component of AWRT has been used recently in a UAS T&E environment. During November and December of 2007, a series of flight tests were conducted at Yuma Proving Ground, AZ (YPG) with DOD instrumentation mounted on a ScanEagle UAS. ARL was asked to provide fine-scale forecasts of winds and turbulence and on-site advisories during the testing, since these Met parameters could have adversely affected the integrity of the data collection from the ScanEagle. Although the optimum routing capabilities of AWRT were not required for this particular field test, its foundational graphical weather impacts display engine was employed. Fig. 4 is an example of one of the ScanEagle test forecasts.

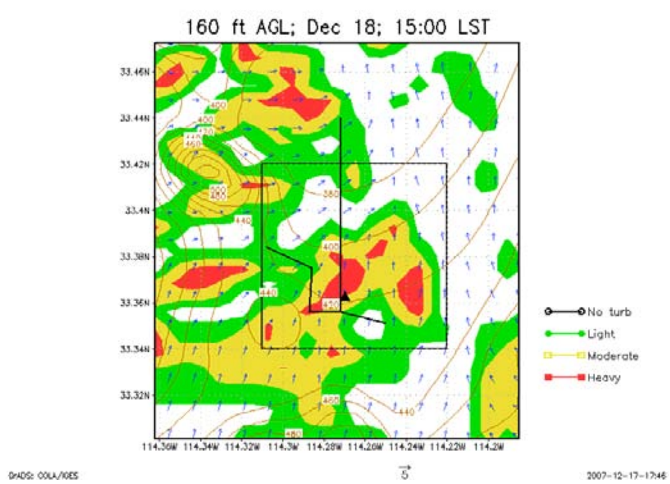

Figure 4. Map view of the YPG ScanEagle UAS flight test area. Color coding of turbulence intensities is indicated in the legend. Wind vectors are shown in grey, with magnitude scale (5 m/s) indicated at the bottom of the plot. Forecast data are for a terrain-following level 160 ft. above the surface.

The full map is a 15 X 15 km area for which a fine-scale Met forecast model was run (1.0 km grid spacing, run for every hour during the daily test window). The inner box depicts the 7 X 7 km area of operations for the UAS. The other lines that fall mostly within the inner box are representations of YPG roads that served as reference points for the UAS pilot. The forecast turbulence intensities and winds were for a terrain-following level 160 ft. above the surface.

Weather impact plots such as that depicted in Fig. 4 proved most valuable to the test coordinators and pilots during the ScanEagle flights at YPG. It is anticipated that future UAS T&E operations might benefit from AWRT's capabilities, to include its optimum routing feature.

4. SUMMARY

ARL has built and successfully demonstrated an aircraft flight mission planning and execution tool for manned and unmanned aircraft which finds an optimal route (using the A* algorithm) when weather is predicted to adversely impact the aircraft and/or on-board systems. Current graphical applications of the AWRT can provide pilots, flight planners, test conductors, and airspace managers with flight route options when such adverse flight weather conditions impact a given airspace. The technology has been shown to benefit flight paths of all lengths and durations via flight route optimization capabilities and 4-D visualizations to increase mission effectiveness. Future machine-to-machine technology will allow for

automated updates of new gridded weather databases to be communicated to flight controllers, flight control computers, and directly to the cockpit, resulting in dynamic rerouting of aircraft en-route as predicted weather conditions change and weather hazards are avoided.

The AWRT technology is being implemented on Army and Air Force weather systems, using both thin and thick client web-enabling capabilities. Such implementations are suitable for civilian airline route planning and en-route updates, general aviation applications, UAS, and for specific Homeland Security unmanned aircraft flights along the borders of the continental United States. Aviation forecasters and flight weather briefers can also significantly benefit from the AWRT, thus providing pilots and aircraft operators with specific flight route grid point weather impacts output with options for routing around hazardous en-route conditions.

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